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ANALYTICAL METHODS REPORT 8605

A SUMMARY OF THE
DEVELOPMENT OF INTEGRAL AERODYNAMIC METHODS FOR
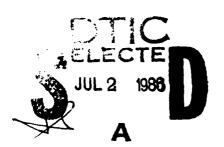# THE COMPUTATION OF ROTOR WAKE INTERACTIONS

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20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

The purpose of the research reported here is to develop basic methodology for a generalized forward flight aerodynamic analysis method for isolated rotors. All of the work thus far has been concerned with the development of integral methods. Efforts have concentrated on analytical modeling studies and code development for fundamental vortex/blade interactions that occur in forward flight. Calculations show that vortex-core deformations can be simulated but that numerical errors in the core growth should be removed in order

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to study such phenomena as bursting. The computed trajectory of a tip vortex passing another wing is also validated with experiment as well as the prediction of vortex-induced separations. The calculation of the rotor wake in hover has been improved and the importance of secondary vortex roll-ups for a modern rotor is discussed. Finally, a time-stepping panel method has been formulated and verified by application to impulsively started wings. A pilot code version for unsteady rotor motions is described along with its preliminary application to a two-bladed rotor.

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1.0 INTRODUCTION AND PROBLEM STATEMENT

Although there has been a great deal of progress in the design of modern helicopters, the design requirements for the next generation rotary wing aircraft pose a serious challenge for the helicopter industry and for the analytical/experimental tools that are currently available. Certainly, increased forward flight performance requirements, including "nap-of-the-earth" operation, demand continued development of existing and advanced technologies for the aerodynamic modeling of the helicopter in forward flight. The rotary wing aircraft in forward flight is fraught with difficult and challenging aerodynamic problems that must be addressed--unsteady separations, highly three-dimensional flows, body rotor interference, wake-blade interactions, and unsteady transonic flows.

As far as isolated rotor performance is concerned, proper modeling of the various wake-blade interactions holds the greatest promise of more accurate analysis. The vortex wake is composed of streamwise filaments due to radial circulation variations and shed bound vortex filaments due to azimuthal circulation variations. Trailing filaments, outboard of the maximum bound circulation, roll up into a concentrated tip vortex core. Of course, this radial position for vortex roll-up is also time dependent. The close passage of these tip vortex filaments to the rotor blades results in rapid fluctuations of the induced velocity field at the blades (radially and azimuthally) and is the dominant source of the higher harmonic airloads. Consequently, the calculation of the force-free tip vortex positions is required for accurate airloads predictions. In addition, a better understanding of the flow physics of close blade tip vortex encounters is evidently also needed to improve the prediction of airloads in forward flight.

The purpose of the research reported here was to develop basic methodology for a generalized forward flight aerodynamic analysis method for isolated rotors. All of the work thus far has been concerned with the development of integral methods. In particular, low-order panel methods for both steady and unsteady flows have been utilized in this work. Efforts have concentrated on analytical modeling studies and code development for fundamental vortex/blade interactions that occur in forward flight. Areas of investigation included the following.

(1) Two- and three-dimensional modeling and calculations of viscous vortex core deformations due to the presence of wing surfaces or other vortical regions.

(2) General techniques for the prediction of vortex sheet geometries including steady-flow computations of wing/vortex encounters and vortex-induced separations.

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(3) Improvements to the calculation of hovering rotor wake geometries and associated rotor performance predictions.

(4) Development and verification of associated unsteady methodology for wings in translation and arbitrary motion.

(5) Formulation and development of an unsteady panel method for rotor airloads and preliminary computations.

The reader is referred to Ref. 1 for the details of this work. Here, a brief summary of the results obtained in the course of these investigations is described below.

2.0 SUMMARY OF RESULTS AND RECOMMENDATIONS

Computational methods have been developed in order to simu-
late vortical regions or cores and the interaction of such cores
with lifting surfaces. The focus in this task was on the compu-
tation of core deformations that occur when regions of enclosed
vorticity interact with a solid surface or other vortex cores
rather than the computation of wing/rotor-induced loadings due to
passing vortex cores. These calculations have shown the
following.

(1) Based upon the work by Rossow (2), a two-dimensional code
    was written to compute the merging of finite vortex cores.
    The vorticity distribution within the core is represented by
    a cloud or cell of discrete point vortices. Once verified,
    the code was coupled with a two-dimensional, time-stepping
    panel code, VORSEP (3), in order to study core deformations
    that occur in the interaction with a solid surface. It was
    found that these methods can be utilized to compute the
    merging of vortex cores and cross-flow interactions with
    wing surfaces between leading and trailing edges; however,
    to effectively study the viscous core deformations along
    with the tip vortex roll-up process a new scheme of multiple
    time scales should be developed to limit the computation
    time required where two roll-ups occur at vastly different
    rates.

(2) The extension of the two-dimensional vortex core model to
    the three-dimensional program has been accomplished. Calcu-
    lations have shown the deformation and transport of the
    vortex-core structure for a close wing passage case. At
    present, the changes in the vortex core due to the interac-
    tion are displayed by comparison with an equivalent isolated
    vortex core calculation in order to remove numerically gen-
    erated core diameter growth. The artificial growth should
    be removed from the calculation by developing a cylindrical
    polar integration scheme centered about the locally computed
    vortex centroid. With numerically generated core growth in
    control, the procedure should then be modified to compute
    local pressures in the core and to investigate the potential
    for vortex burst criteria.

Several improvements were installed in program VSAERO (a
steady flow panel method, Vortex Separation AEROdynamics) in the
course of investigating the computation of vortex trajectories
(1). Studies of wing-vortex filament (infinitesimal cores) en-
counters including computed geometries and vortex-induced separa-
tions are reported in Ref. 4. In comparisons with experimental
data (5), it was found that

(1) The computed tip-vortex geometry compares very well with experimental data.

(2) The program does appear to predict correctly the occurrence of vortex-induced separations on a particular wing.

(3) The computed wing loads and chordwise pressures for a wing with massive separation compares well with experimental data. This, however, is achieved by setting, 'a priori', the vorticity jump across the wake sheet.

(4) Improvements in the wake separation auxiliary conditions are required before the shed vorticity in closed separations can be automatically computed.

(5) A new computation model should be developed to simulate partial span separations, and, for the rotor case, the inclusion of a three-dimensional boundary layer method should be investigated.

A thin lifting-surface method, program HOVER, for the prediction of hover/climb airloads was developed by Analytical Methods, Inc. a number of years ago. The program development was described in 1979 in Ref. 6. Until recently, wakes were relaxed in the axial direction only while the radial coordinates were constrained to the prescribed wake locations in order to control numerical instabilities in the calculation of wake position. Under the current contract, a grid plane relaxation procedure for rotary flow and a tip vortex/wake regeneration technique were developed in order to obtain the radial contraction deformations as well as axial deformations of rotor wakes in hover. The basic method and its application were described in Ref. 7. The new wake procedures installed in program HOVER have shown:

(1) Stable, free-wake geometries for rotors in hover are computed.

(2) Calculations of wake geometries for traditional rotors compare very well with measurements.

(3) The wake structure for a modern rotor does not trend with current prescribed wake empirical equations. The presence of secondary vortex roll-ups are important features of the wake structure that must be modeled.

The calculation of unsteady wing motions has been used in the present contract to develop the basic program method and to verify the analysis of unsteady motions before proceeding to the much more complicated case of a rotor in forward flight. Fortunately, a time-stepping version of VSAERO was concurrently

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being developed under NASA funding for calculating the unsteady aerodynamic characteristics of wings oscillating in pitch (8). The program, VSAERO-TS, has formed the basis of the investigation reported here. In this contract, the program was modified by utilizing some of the methods in Ref. 9 in preparation of eventual use as a basic method for rotors. Studies have shown:

(1) The computation of the time history for an isolated wing starting impulsively from rest compares favorably with other theoretical methods. The roll-up of the starting vortex is also computed in the method.

(2) The program now allows for a schedule of an arbitrary angle-of-attack motion to be prescribed. Preliminary computation for an isolated wing in general motion shows the development of the time-dependent wake structure. This part of the code should be checked in detail. In particular, the unsteady Kutta condition for arbitrary motion should be investigated and apparent mass and circulatory parts of the total forces should be computed separately in future work.

(3) The wake development and time history of wing loads for two wings in tandem show the capability of the unsteady code for simulating very close wake interactions. In this case, the unsteady loading on the following wing is explained by apparent mass and circulatory contributions due to the starting vortex as it passes over the wing. The apparent mass term reaches a maximum as the vortex passes the 1/4 chord point while the circulation part reaches its maximum as the vortex passes the 3/4 chord point.

Finally, the development of a time-stepping panel code for the calculation of unsteady rotor airloads in forward flight is still in the formation stage. The unsteady code described above has been modified to simulate some of the physical flow features associated with rotors in forward flight, but is still not thoroughly checked or validated even for simple cases. Rotary motion, control axis tilt, and multiple blades have been included in the time-stepping panel method. The program application has shown:

(1) The calculated unsteady wake for a two-bladed rotor is qualitatively correct--expected trends such as more rapid tip-vortex roll-up on the advancing side than on the retreating side, and a general upwash ahead and downwash behind the rotor disk is computed.

(2) Comparisons of preliminary blade loads for undeformed and deformed wakes show that the general program method is functioning correctly.

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(3)   More detailed calculations including increased blade
      paneling and decreased time-step size should be completed
      before conclusions regarding the accuracy of the method.
      Enhanced graphics methods will also be necessary in order to
      analyze the computed wake deformations more carefully.

(4)   In addition, a nonrotating frame of reference needs to be
      added to the code so that the prescribed wake module can be
      utilized (Ref. 10), and so that blade and wake motions can
      be more easily viewed. Of course, blade cyclic must be
      installed in the code before realistic computations in for-
      ward flight can be made. Coupling with the harmonic analy-
      sis module should also be completed in order to compute the
      forward flight performance.

3.0 LIST OF PUBLICATIONS SUPPORTED BY THIS CONTRACT

In the course of this contract, several technical papers that were either partially or completely supported by this contract were published. The list is as follows.

1. Summa, J.M., "Advanced Rotor Analysis Methods for the Aerodynamics of Vortex-Blade Interactions in Hover", _Vertica_, Vol. 9, No. 4, 1985.

2. Nathman, J.K., "Estimation of Wake Roll-up over Swept Wings", AIAA 84-2174, August 1984.

3. Maskew, B., "Predicting Aerodynamic Characteristics of Vortical Flows on Three-Dimensional Configurations using a Surface-Singularity Panel Method", _AGARD CP-342_, Paper No. 13, April 1983.

4. Summa, J.M., "The Calculation of Vortex-Core Deformation with an Integral Method", To be submitted for publication.

4.0 LIST OF PERSONNEL SUPPORTED BY THIS CONTRACT

The list of personnel at Analytical Methods, Inc. that were supported by this contract is:

Dr. J. Michael Summa

Dr. Brian Maskew

Dr. J.K. Nathman

Dr. B.M. Rao

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